Combination of Hot-Water Surface Pasteurization of Whole Fruit and Low-Dose Gamma Irradiation of Fresh-Cut Cantaloupe†

XUETONG FAN,[1]* BASSAM A. ANNOUS,[1] KIMBERLY J. B. SOKORAI,[1] ANGELA BURKE,[1] AND JAMES P. MATTHEIS[2]

[1]*Eastern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, 600 East Mermaid Lane, Wyndmoor, Pennsylvania 19038; and* [2]*Tree Fruit Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, 1104 North Western Avenue, Wenatchee, Washington 98801, USA*

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ABSTRACT

Improvements in methods for disinfecting fresh-cut cantaloupe could reduce spoilage losses and reduce the risk of foodborne illness from human pathogen contamination. The objective of this study was to investigate the feasibility of using hot-water treatment in combination with low-dose irradiation to reduce native microbial populations while maintaining the quality of fresh-cut cantaloupe. Whole cantaloupes were washed in tap water at 20 or 76°C for 3 min. Fresh-cut cantaloupe cubes, prepared from the washed fruit, were then packaged in clamshell containers, and half the samples were exposed to 0.5 kGy of gamma radiation. Native microflora populations and sensory qualities were evaluated during the subsequent 7 days of storage at 4°C. The hot-water surface pasteurization reduced the microflora population by 3.3 log on the surface of whole fruits, resulting in a lower microbial load on the fresh-cut cubes compared with cubes cut from fruit treated with cold water. Irradiation of cubes prepared from untreated fruit to an absorbed dose of 0.5 kGy achieved a low microbial load similar to that of cubes prepared from hot-water-treated fruit. The combination of the two treatments was able to further reduce the microflora population. During storage, the headspace atmosphere of the packages was not significantly influenced by any of the treatments. Color, titratable acidity, pH, ascorbic acid, firmness, and drip loss were not consistently affected by treatment with irradiation, hot water, or the combination of the two. Cubes prepared from hot-water-treated whole fruit had slightly lower soluble solids content. The combination of hot-water pasteurization of whole cantaloupe and low-dose irradiation of packaged fresh-cut melon can reduce the population of native microflora while maintaining the quality of this product.

Consumption of fresh-cut produce has increased at an annual rate of approximately 10% since 1995 because of convenience of use and health benefits *(15)*. The sale of fresh-cut fruit is expanding even more rapidly and is gaining a large share of the produce market, approaching 1 billion U.S. dollars in sales per year *(15)*. Processing of fresh-cut fruits involves washing, peeling, cutting, and packaging. During cutting and peeling, pathogens on the surface of whole fruit may be transferred onto fresh-cut pieces.

Fresh-cut cantaloupe, either as a single component product or as part of multifruit salad, is available all year in the United States. However, consumption of cantaloupe has been linked to a number of U.S. outbreaks, mostly associated with *Salmonella*. Between 1990 and 2000, more than 700 salmonellosis cases were reported in the United States and Canada *(32)*. In 2001 and 2002, numerous cases of salmonellosis and two deaths were associated with consumption of imported cantaloupe in the United States and Canada *(32)*. As a result, the U.S. Food and Drug Administration (FDA) *(32)* issued guidelines for safe handling of melons at retail in which they recommended that fresh-cut melons be consumed within 7 days. Recent FDA surveys revealed that a higher incidence of contamination was found on both imported and domestic whole cantaloupe compared with many other fruits and vegetables *(33, 34)*. About 2.4 and 0.6% of domestically produced cantaloupes and 5.3 and 2.0% of imported cantaloupes were positive for *Salmonella* and *Shigella*, respectively. The high rates of pathogen contamination of whole melons highlight the possibility of pathogen contamination of fresh-cut cantaloupe. Food safety intervention technologies are needed for both whole and cut melons.

Many antimicrobial rinses have been investigated for their effectiveness. Chlorine is routinely used as a sanitizer by produce processors, but its effectiveness is limited, achieving only a 2- to 3-log reduction of native microflora on whole cantaloupe *(29)*. The use of chlorine also is a concern because of the potential formation of harmful by-products *(24)*. Other antimicrobial agents also have limited effectiveness for reducing the microbial population on the surface of cantaloupes *(25, 27)*, partially because of the rough surface (netting). Ukuku et al. *(30)* demonstrated that immersion of inoculated cantaloupe in hot water or a 5% hydrogen peroxide solution at 70°C for 1 min resulted in up to a 3.8-log CFU/cm^2 reduction in *Salmonella*. Annous et al. *(1)* reported that surface pasteurization in a commercial-size surface pasteurizer with hot water at 76°C for 3 min resulted in more than a 5-log reduction in *Salmonella*

* Author for correspondence. Tel: 215-836-3785; Fax: 215-233-6445; E-mail: xfan@errc.ars.usda.gov.

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enterica Poona and *Escherichia coli* populations on inoculated cantaloupes. This process also led to increased shelf life of whole cantaloupes by reducing the population of spoilage microorganisms on the rind surface. Fleischman et al. *(11)* demonstrated the effectiveness of hot-water treatment for the reduction of *E. coli* O157:H7 on the surface of whole apples. Mild heat treatments have been used as a nonchemical method to control fungal and bacterial rot in various fruits and vegetables *(5, 19)*. Delaquis et al. *(6)* demonstrated that microbial populations on lettuce washed in chlorinated water at 4 or 47°C for 3 min were reduced by 1 and 3 log, respectively. Li et al. *(18)* reported that treatment with water at 50°C for 1.5 min with or without chorine reduced the population of mesophilic aerobic microflora on lettuce by 1.7 to 2.0 log.

Ionizing radiation is an effective nonthermal technology that can be used to inactivate many foodborne pathogens on fresh fruits and vegetables *(20, 26)*. However, at high doses, irradiation can cause undesirable quality changes, such as loss of firmness. Therefore, a combination of low-dose irradiation with other sanitizing technologies may be useful for ensuring the safety of produce without adverse effects on product quality. Fan et al. *(10)* found that a combination of warm water and irradiation maintained the quality of fresh-cut lettuce. Palekar et al. *(22)* treated whole cantaloupe with chlorine followed by low-dose electron beam irradiation of the cut fruit and found that the combination treatments reduced bacterial load and extended shelf life but did not affect color, flavor, or texture of cut pieces. Thus, decontamination of whole cantaloupe before cutting using a chlorine wash in combination with low-dose irradiation of the cut fruit may be used to extend product shelf life.

Although hot water can reduce the population of microorganisms on the surface of cantaloupes, potentially reducing the number of microorganisms on the fresh-cut fruit, fresh-cut pieces can be recontaminated during cutting, handling, and packaging. Irradiation is used as a terminal step, i.e., a postpackaging treatment, therefore ensuring microbial safety prior to consumption. Although low-dose irradiation or mild heating will not significantly affect the quality of the produce, high-dose irradiation and/or excessive heating can adversely impact product quality. The possible influences of combinations of these two food safety interventions on the quality of fresh-cut cantaloupe are unclear. Therefore, the objective of this study was to investigate the effect of hot-water treatment of whole cantaloupe prior to cutting followed by low-dose irradiation of fresh-cut pieces prepared from the treated melons on indigenous microbial population and quality of fresh-cut melon during storage at 4°C.

MATERIALS AND METHODS

Cantaloupes (*Cucumis melo* L. var. *cantalupenis* Naud cv. Acclaim) of South American origin were purchased through a local supermarket. Melons with bruising and compression damage were discarded. The melons were stored at 4°C for no more than 2 days before being used. The average weight of each melon was about 1,250 g.

Treatment of whole fruit. Sets of six whole melons were placed in a covered stainless steel basket and submerged in a commercial-size stainless steel dump tank containing 1,000 liters of tap water at 20 or 76 ± 0.5°C for 3 min. Water jets provided mechanical agitation of the melons during the water treatments. Individual melons were then immediately sealed in zipped plastic bags and submerged for 5 min in a stainless steel tank containing 160 liters of ice water. Most of the air in the plastic bag was removed before sealing to ensure rapid heat transfer during the cooling process. These treatments were repeated four times, resulting in 24 melons per water treatment per experiment. After treatment, fresh-cut cubes were prepared from the cantaloupes. A detailed description of the treatments and temperature profiles at various depths of melons was published previously *(1)*.

Preparation of cantaloupe cubes. All preparations were conducted in a food processing cold room (8°C) under strict sanitary conditions. All utensils and equipment used for preparing fresh-cut pieces were sanitized by immersion in 200 ppm chlorinated water for 5 min. After the water treatment, the melons were uniformly peeled with a mechanical fruit peeler as previously described *(1)*. The rinds were weighed and saved for microbial analysis. The peeled melons were sliced once longitudinally, seeds were removed, and the seed cavity was cleaned manually. Halves were cut into approximately 2- to 3-cm slices, and cubes were prepared from the slices. The average weight of the cubes was 13.2 ± 4.6 g. For replicates of each experiment, cubes from three fruits were randomized, and cubes weighing 375 ± 10 g were placed into 6-oz (180-ml) polystyrene clamshell containers (Dart Container Corp., Mason, Mich.). Polystyrene is an FDA-approved packaging material for irradiated food *(31)*. Fresh-cut cubes were equilibrated at 4°C for 4 h, and half the samples were irradiated to an absorbed dose of 0.5 kGy at 4 ± 2°C. All fresh-cut samples were then stored for up to 7 days at 4°C. Following 0, 1, 3, and 7 days of storage, samples were analyzed for firmness, color, soluble solids content (SSC), pH, titratable acidity (TA), drip loss, ascorbic acid concentration, and headspace O_2 and CO_2 concentrations within the packages. Rinds from melons and fresh-cut cubes samples were analyzed for total aerobic microorganisms.

Irradiation and dosimetry. Cantaloupe cubes were irradiated with a self-contained cesium-137 gamma radiation source (Lockheed Georgia Company, Marietta, Ga.) at a dosage of 0.091 kGy/min. Variations in radiation dose absorption were minimized by placing the samples within a uniform area of the radiation field, irradiating them within a polypropylene container (4-mm wall) to absorb Compton electrons, and using the same geometry for sample irradiation during the entire study. During irradiation, temperature in the radiation chamber was maintained at 4 ± 2°C by flushing the gas phase of liquid nitrogen into the upper portion of chamber. Targeted radiation doses were achieved by varying the exposure time to the radiation field and were verified by placing 5-mm-diameter alanine dosimeter pellets (Bruker, Inc., Billarna, Mass.) with the samples. Alanine pellet doses were assessed with an EMS 104 EPR analyzer (Bruker) and compared with a standard curve. Actual dose was typically within 5% of the targeted doses.

Sampling protocols for total aerobic microorganisms. Whole rinds from each melon or 100 g of cubes were combined with four times as much (wt/vol) 0.1% peptone water (PW; BBL, Becton Dickinson, Sparks, Md.) and blended at medium speed for 1 min with a commercial blender model 51BL31 (Waring Products, Torrington, Conn.). The resulting homogenate was filtered through a filter bag (Spiral Biotech, Bethesda, Md.), and duplicate 10-ml filtrate samples were transferred to sterile tubes. Filtrates

were then diluted in PW as needed and surface plated onto tryptic soy agar (BBL, Becton Dickinson). The plates were incubated for 24 h at 37°C, and resultant colonies were counted manually. The total aerobic bacterial counts were expressed as CFU per square centimeter of rind or per gram of cubes. The surface area of whole cantaloupes was calculated as previously described by Annous et al. *(1)*.

Headspace atmosphere in packages. On each day of quality analysis, 0.5-ml samples of the headspace atmosphere were withdrawn from each package with an airtight syringe and analyzed with a series 580 gas chromatograph (Gow-Mac Instruments, Bridgewater, N.J.) equipped with a 183-cm CTR I column (Alltech Associates, Inc., Deerfield, Ill.) and a thermal conductivity detector. The CTR I column consists of an outer column (0.64-cm inside diameter) packed with an activated molecular sieve and an inner column (0.32-cm inside diameter) packed with a porous polymer mixture. The melon cubes in the packages were then used for subsequent quality analysis.

Texture evaluation. On each sampling day, five fresh-cut cubes from each replicate package were selected. Penetration tests were conducted on the cubes with a TA-XT2i texture analyzer (Texture Technologies Corp., Scarsdale, N.Y.) as previously described by Fan et al. *(8)*. Cubes were cut to achieve a level surface for analysis. A 6-mm-diameter probe was used to penetrate the midpoint between the rind and the core ends of samples to 10 mm at a speed of 10 mm/s. Maximum force (kg) and area under the curve were recorded using Texture Expert version 1.22 software (Texture Technologies).

Color analysis. Color was measured with a ColorQuest XE colorimetric spectrophotometer (Hunter Associates Lab, Reston, Va.) at a 1-cm measuring aperture. The spectrophotometer was calibrated with the standard light trap and a white tile ($L^* = 93.50$, $a^* = -0.89$, and $b^* = 1.01$). D65/10° were used as the illuminant/viewing geometry. Surface color of five cubes from each replicate of each treatment was measured; L*, a*, and b* were recorded at two opposite sides of each cube. Measurements were made at the midpoint between the rind and core ends. Hue and chroma values were calculated with the following equations: Hue $= \tan^{-1}(b^*/a^*)$, and chroma $= (a^{*2} + b^{*2})^{1/2}$.

TA, pH, and SSC. Juice was extracted from cantaloupe cubes with a Champion MAR-48C juicer (Plastaket MFG Co., Lodi, Calif.) and stored at −20°C until analysis. For analysis, samples were thawed at 4°C overnight. The pH was recorded before titration, and TA was measured by titrating a 5-ml aliquot of juice to pH 8.1 with 0.1 N NaOH with an autotitrator (Radiometer Analytical, Lyon, France) and expressed as milligrams of malic acid per 100 ml of juice. SSC was measured with a hand-held refractometer at ambient temperature (~23°C).

Analysis of ascorbic acid. Ascorbic acid was measured according to method of Graham and Annette *(13)* with minor modifications *(9)*. Samples (10 g) were homogenized with 20 ml of 5% (62.5 mM) metaphosphoric acid in a homogenizer (Virtishear, Virtis, Gardiner, N.Y.) at a speed setting of 70 for 1 min. The homogenate was filtered through four layers of cheesecloth, and the filtrate was then centrifuged at 12,000 × *g* for 10 min at 5°C in a Sorvall RC2-B refrigerated centrifuge (Kendro Laboratory Products, Newtown, Conn.). The supernatant was filtered through a 0.45-μm-pore-size Acrodisc LC 13 PVDF syringe filter (Gelman Sciences, Ann Arbor, Mich.) before being analyzed with a Hewlett Packard Ti series 1050 high-pressure liquid chromatography (HPLC) system (Agilent Technologies, Palo Alto, Calif.). The HPLC system consisted of an autosampler, an integral photodiode-array detector, an autoinjector, and a Hewlett-Packard Rev. A02. 05 Chemstation. Injection volume was 20 μl. Separation of compounds was achieved with an Aminex HPX-87H organic acids column (300 by 7.8 mm) fitted with a microguard cation H+ (Bio-Rad Laboratories, Hercules, Calif.) eluted with a mobile phase of 5 mM sulfuric acid at a flow rate of 0.5 ml·min^{-1}. Column temperature was maintained at 30°C with a column heater (Bio-Rad). Ascorbic acid concentration was monitored at 245 nm and calculated from an ascorbic acid standard curve.

Drip loss. The overall weight of samples and amount of juice accumulated in the clamshell containers were determined at 0, 1, 3, and 7 days of storage. Drip loss was expressed as a percentage of the juice divided by the overall weight of the melon cubes in the containers.

Statistical analysis. The experimental design was a randomized complete block design with four replicates. Analysis of variance was used to determine significant differences ($P < 0.05$) among population means in response to hot water and irradiation and to evaluate the interaction between the treatments. The least significant difference test was used within storage times to evaluate treatment effects and was used within treatments to evaluate storage effects. All statistical analyses and calculations of means and standard deviations (SDs) were performed with SAS software (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Effects of surface pasteurization and irradiation on total aerobic microbial populations. Mean ± SD residual total aerobic microflora on the whole rind of unwashed cantaloupe and on those washed at 20 or 76°C for 3 min were 5.7 ± 0.9, 5.5 ± 0.7, and 3.3 ± 0.4 log CFU/cm^2, respectively. Overall, surface pasteurization at 76°C for 3 min resulted in a significant reduction ($P < 0.05$) in indigenous bacteria (2.4 log CFU/cm^2) on the surface of whole melon. Similar reductions after treatment with hot water at 76°C for 3 min were previously reported by Annous et al. *(1)*. There was no significant difference in total aerobic microflora between the unwashed controls and the melons washed at 20°C for 3 min, which indicates that washing with water at 20°C did not dislodge bacterial cells attached to the surface of the melon. Resistance to washing with water at 20°C could be due to the attachment of bacterial cells to inaccessible sites or to biofilm formation on the rind of the melon *(1)*. The effectiveness of hot-water treatments has been demonstrated previously *(1, 30)* but is dependent on the length of treatment and the temperature of the water. At high temperatures and long treatment times, tissue damage may occur, resulting in darkening and translucency of tissues under the rind.

The effect of surface pasteurization and/or irradiation on the residual microbial population on fresh-cut melon following storage of up to 7 days is shown in Table 1. Hot-water surface pasteurization of whole melon resulted in a significantly lower bacterial population on cut melon cubes than on control cubes (washed at 20°C and no irradiation) on day 0. Irradiation of the cut melons also resulted in a significantly lower bacterial population than on the control cubes on day 0. The combination of surface pasteurization and irradiation resulted in small further reductions (0.5 to

TABLE 1. *Effect of surface pasteurization and/or irradiation on residual microbial populations on fresh-cut cantaloupes following storage at 4°C*[a]

Storage time (days)	Microbial population (log CFU/g)			
	Cold water		Hot water	
	0 kGy	0.5 kGy	0 kGy	0.5 kGy
0	3.4 ± 0.8 A	2.0 ± 1.2 B	1.9 ± 1.0 B	1.4 ± 1.6 B
1	3.9 ± 0.6 A	2.5 ± 1.5 AB	2.2 ± 1.2 B	1.8 ± 1.4 B
3	3.7 ± 1.2 A	3.1 ± 2.2 A	2.6 ± 1.5 A	1.9 ± 1.9 A
7	4.8 ± 0.9 A	3.0 ± 1.9 AB	2.7 ± 1.8 B	2.1 ± 1.6 B
LSD[b]	1.0	2.1	1.7	2.0

[a] Whole melons were washed in cold water (20°C) or hot water (76°C) for 3 min. Cut pieces prepared from the washed melons were then exposed to 0 or 0.5 kGy of gamma radiation. Mean (±SD) microbial populations on cut pieces were determined following subsequent storage at 4°C. Within the same storage period, means with the same letters are not significantly different ($P > 0.05$).

[b] The least significant difference ($P < 0.05$) for the storage effect.

0.6 log) in bacterial populations on the cut pieces, although these differences were not significant compared with those for the treatments separately at day 0. Similar reductions resulting from these treatments were observed during storage. After 7 days of storage, cut samples prepared from melons treated with hot-water pasteurization maintained a lower population of bacteria. Compared with the control cubes, cubes from hot-water-treated fruit had aerobic bacterial populations that were 2.1- and 2.7-log lower in nonirradiated and irradiated samples, respectively, whereas irradiation alone achieved a 1.8-log reduction.

Overall, there was no significant difference among the three treatments (irradiated sample prepared from melons treated with cold water and irradiated and nonirradiated samples from melons treated with hot water) at any storage day. Hot-water surface pasteurization of whole melon achieved similar reductions in aerobic bacteria as did irradiation of fresh-cut pieces prepared from melons treated with cold water. The combination of the two treatments resulted in small (0.4- to 1.2-log), no significant reductions in aerobic bacteria compared with the results of either treatment alone. The effectiveness of hot-water treatment indicated the importance of cleaning whole cantaloupes before preparation of cut pieces. Cut melon cubes were mostly contaminated via transfer of microorganisms from the surface to the interior during cutting and preparation.

A small but significant increase in bacterial populations ($P < 0.05$) was observed in the control fresh-cut melon cubes during storage, but there was no significant increase in the bacterial population for cubes from other treatments. The nonsignificant bacterial growth during storage following these treatments may be indicative of injury to the surviving microflora or of reduced initial populations of psychrotrophic bacteria.

Effect of surface pasteurization and irradiation on quality of fresh-cut cantaloupes. The headspace CO_2 in the packages did not accumulate to high concentrations during storage (Table 2). On days 0, 1, and 3, the samples from melons treated with hot water followed by irradiation always had the highest CO_2 concentrations, although the difference among the treatments was not always significant. During storage, CO_2 concentrations increased from day 3 to day 7 in samples prepared from melons treated with cold water but did not significantly change in samples prepared from melons treated with hot water. Overall, irradiation or hot-water surface pasteurization did not have consistent effects on CO_2 concentrations. The O_2 concentrations in the samples treated with hot water without irradiation were significantly higher than that of the control on day 1, suggesting that the hot-water treatment may temporarily raise the respiration rate by increasing consumption of O_2. During storage, O_2 concentrations in the packages generally decreased for all treatments. Our results suggest that the atmosphere in the packages did not change dramatically during storage and that high concentrations of CO_2 did not accumulate. The clamshell packages, which are commonly used for fresh-cut fruits, may not support the optimum atmosphere for fresh-cut cantaloupes. O'Connor-Shaw et al. *(21)* suggested that surface-sterilized cantaloupe pieces could be stored for up to 28 days under a controlled atmosphere of 6 to 15% CO_2 and 3.5 to 5% O_2 at 4.5°C without significant loss of quality. Ayhan and Chism *(2)* found that fresh-cut cantaloupes sterilized with high concentrations of NaOCl and stored at 5% O_2 and 2°C had a shelf life of 15 days.

On day 1, the SSC of irradiated samples prepared from melons treated with hot water was significantly lower than that prepared from control melons, but the SSC for the other two treatments did not differ significantly from that of the control (Table 3). By day 3, all three treatments had significantly reduced SSC compared with that of the control, and on day 7, a significant reduction in SSC was observed in the nonirradiated cubes prepared from melons pasteurized with hot water. The highest SSC was always observed for the control samples during the 7-day storage period. The lowest SSC was generally observed in samples prepared from melons treated with hot water regardless of irradiation. Overall, hot-water washing of whole melons significantly reduced SSC of cut melon (7.5 versus 8.3%). Lester *(16)* found that hot-water treatment of cantaloupes (57°C for 3 min) did not affect SSC.

The pH of melon cubes was not affected by any treat-

TABLE 2. *Effect of hot-water treatment, irradiation, and storage on concentrations of headspace CO_2 and O_2 in packages of fresh-cut cantaloupes*[a]

Storage time (day)	Cold water		Hot water	
	0 kGy	0.5 kGy	0 kGy	0.5 kGy
CO_2 (%)				
0	1.7 ± 0.4 B	2.1 ± 0.6 AB	2.1 ± 0.1 AB	2.4 ± 0.2 A
1	2.2 ± 0.4 B	2.5 ± 0.6 AB	2.2 ± 0.6 B	2.6 ± 0.7 A
3	2.4 ± 0.8 AB	1.6 ± 0.5 B	2.9 ± 1.4 A	3.2 ± 1.3 A
7	3.2 ± 1.7 B	4.4 ± 2.9 A	2.4 ± 1.5 B	3.1 ± 1.6 B
LSD[b]	1.1	1.5	0.9	0.8
O_2 (%)				
0	19.6 ± 0.8 BC	19.1 ± 0.8 C	20.8 ± 0.8 A	20.2 ± 0.6 AB
1	17.4 ± 2.3 AB	16.5 ± 1.6 B	17.5 ± 1.3 A	17.0 ± 2.3 AB
3	14.6 ± 4.3 A	15.7 ± 2.8 A	16.1 ± 2.7 A	14.0 ± 2.6 A
7	16.1 ± 3.7 A	10.2 ± 8.1 B	16.2 ± 1.5 A	14.8 ± 3.4 AB
LSD	3.4	4.3	1.9	2.4

[a] Whole melons were washed in cold water (20°C) or hot water (76°C) for 3 min. Cut pieces prepared from the washed melons were packaged in clamshell containers and then not irradiated (0 kGy) or irradiated at 0.5 kGy. Mean (±SD) CO_2 and O_2 concentrations were analyzed during subsequent storage at 4°C. Within the same storage period, means with the same letters are not significantly different ($P > 0.05$).

[b] The least significant difference ($P < 0.05$) for the storage effect.

ment on days 1 or 7 (Table 3). On day 3, fruit cubes prepared from melons treated with hot water with or without irradiation had a lower pH than did cubes prepared from melons treated with cold water. There were no significant differences in TA among the treatment groups. However, TA consistently decreased during storage, although these differences were not always significant. Earlier studies indicated that heat treatment increased the sweetness and lowered the acidity of some fruits *(23)*. In the present study, we did not observe any significant change in TA, but a decrease in SSC was found on most storage days.

There were no significant differences in firmness among the treatments on any storage day, and firmness did not change significantly during storage (Table 3). Overall the firmness of melon cubes was not significantly affected by irradiation or hot-water treatment. Palekar et al. *(22)* reported that no significant change in firmness was observed after irradiation at 0.7 kGy but a significant loss in firmness was found at 1.4 kGy. One of the most commonly observed changes in many fruits as a result of heat treatment is softening *(23)*. In the present study, we did not observe any significant change in firmness of melon cubes due to hot water treatment of whole melons. During hot-water treatment, only the surface and the tissues immediately under the rind were heated *(1)*. Heat did not penetrate far enough into the flesh to affect the texture of the edible portion of the melons. During processing of fresh-cut cantaloupes, the rinds and some outer flesh were removed and discarded so that tissues damaged by the hot-water treatment were rare in the final fresh-cut product.

There was no significant difference in drip loss among the treatment groups on any storage day (Table 3), but drip loss was significantly higher on day 7 than on days 1 and 3, suggesting the deterioration of fruit integrity during storage.

No significant differences in ascorbic acid concentration were observed among the treatments, and ascorbic acid concentration did not change significantly during the 7 days of storage (Table 3). Overall, cubes prepared from melons treated with hot water (and either irradiated or not irradiated) tended to have lower ascorbic acid concentrations than did cubes prepared from melons treated with cold water (246.9 μg/ml for cold-water treatment versus 221.2 μg/ml for hot-water treatment).

The L* values (lightness) of fresh-cut melon cubes were not significantly different among the treatment groups on days 1 and 7 (Table 4). On day 3, the irradiated samples prepared from melons treated with either cold or hot water had lower L* values than did the nonirradiated samples from melons treated with hot water. On day 1, the hue values of samples from melons treated with hot water were higher than those of the control cubes, but after 7 days of storage there was no significant difference in hue values among the treatment groups. There was no difference in chroma values between the control and the other three treatment groups on any storage day. Thus, storage had no significant effect on chroma values.

Overall, cubes prepared from melons treated with hot water had similar L* values and chroma values and higher hue values than did cubes from melons treated with cold water. Nonirradiated samples prepared from melons treated with hot water always had the highest L* values, suggesting that these samples were the lightest. Irradiation had no effect on a*, b*, hue, or chroma values but decreased L* values. Generally, no consistent effect of any of the treatments was observed for any of the color parameters during storage.

Irradiation and hot water applied separately or in combination have been studied commercially for the purposes of disinfection, pathogen reduction, decay control, and

TABLE 3. *Effect of hot-water treatment, irradiation, and storage on soluble solids content (SSC), pH, titratable acidity (TA), firmness, drip loss, and ascorbic acid content of fresh-cut cantaloupes*[a]

Storage time (days)	Cold water		Hot water	
	0 kGy	0.5 kGy	0 kGy	0.5 kGy
SSC (%)				
1	9.1 ± 0.6 A	9.1 ± 0.4 A	8.6 ± 0.5 AB	8.0 ± 1.0 B
3	8.7 ± 1.3 A	7.2 ± 0.6 B	6.9 ± 1.0 B	7.1 ± 1.2 B
7	8.2 ± 0.8 A	7.6 ± 1.4 AB	7.2 ± 1.3 B	7.5 ± 0.9 AB
LSD[b]	1.1	1.0	1.3	1.3
pH				
1	6.5 ± 0.2 A	6.6 ± 0.0 A	6.4 ± 0.1 A	6.5 ± 0.1 A
3	6.6 ± 0.3 A	6.6 ± 0.2 A	6.4 ± 0.1 B	6.4 ± 0.1 B
7	6.5 ± 0.1 A	6.5 ± 0.2 A	6.6 ± 0.1 A	6.6 ± 0.2 A
LSD	0.2	0.2	0.1	0.1
TA (mg malic acid/100 g of juice)				
1	0.095 ± 0.010 A	0.098 ± 0.019 A	0.095 ± 0.007 A	0.090 ± 0.012 A
3	0.085 ± 0.013 A	0.073 ± 0.015 A	0.075 ± 0.015 A	0.071 ± 0.019 A
7	0.082 ± 0.009 A	0.079 ± 0.025 A	0.081 ± 0.023 A	0.082 ± 0.012 A
LSD	0.014	0.023	0.021	0.019
Maximum force (kg)				
1	1,497 ± 528 A	1,269 ± 478 A	1,365 ± 522 A	1,308 ± 393 A
3	1,452 ± 488 A	1,298 ± 415 A	1,312 ± 449 A	1,301 ± 375 A
7	1,364 ± 485 A	1,377 ± 359 A	1,264 ± 482 A	1,338 ± 608 A
LSD	1,010	790	896	961
Drip loss (%)				
1	7.8 ± 1.1 A	8.2 ± 2.3 A	6.8 ± 1.5 A	8.0 ± 1.8 A
3	9.0 ± 1.8 A	8.5 ± 2.1 A	8.2 ± 1.1 A	8.6 ± 1.9 A
7	11.7 ± 2.1 A	11.2 ± 4.4 A	10.7 ± 1.8 A	10.9 ± 1.8 A
LSD	2.2	4.0	1.6	1.6
Ascorbic acid (μg/g of fresh weight)				
1	214.1 ± 58.1 A	215.6 ± 36.5 A	214.7 ± 50.0 A	200.8 ± 60.3 A
3	271.8 ± 72.0 A	249.4 ± 58.4 A	227.5 ± 50.3 A	231.7 ± 29.5 A
7	265.5 ± 30.0 A	264.8 ± 50.1 A	245.9 ± 29.6 A	202.8 ± 56.6 A
LSD	67.7	62.4	56.4	64.1

[a] Whole melons were washed in cold water (20°C) or hot water (76°C) for 3 min. Cut pieces prepared from the washed melons were then exposed to 0 or 0.5 kGy of gamma radiation. Effects (mean ± SD) were analyzed during subsequent storage at 4°C. Within the same storage period, means with the same letters are not significantly different ($P > 0.05$).

[b] Least significant difference ($P < 0.05$) for the storage effect.

quality improvement of many fruits *(12, 14, 16, 26)*. In the present study, we combined the two treatments at separate stages of fruit processing: hot-water treatment of whole fruits and low-dose irradiation of cut fruit after packaging. Low-dose irradiation applied after hot-water treatment resulted in only a small further reduction in microorganisms, probably because of the already low population of native microflora in fresh-cut melons as a result of the hot-water treatment.

The combination of hot water and irradiation can be applied easily on a commercial scale. Thermal treatment is a common technology used by the food industry. The equipment used for surface pasteurization of whole fruit in the present study was a commercially scaled dump tank. Irradiation has been approved for use on fruits and vegetables to a maximum dose of 1.0 kGy *(26, 31)*, although regulation does not specify its use for fresh-cut fruits and vegetables. Earlier studies have indicated that both hot-water surface pasteurization and irradiation are effective for inactivating foodborne pathogens *(1, 20)*. The combination of the two treatments can be used to achieve microbial safety and maintain the quality of fresh-cut cantaloupes. These treatments have potential application for other fruits, such as honeydew and watermelon.

Although hot-water treatment alone can achieve significant microbial reduction or even sterilize the surface of cantaloupe, very high temperatures or long treatments may damage fruits. Even if the fruit were sterilized, pathogens or spoilage microorganisms present in the environment or on equipment could be transferred to cut cantaloupe during processing, resulting in a contaminated product. Reduction of background microflora from the surface of whole cantaloupe by hot-water treatment, thus reducing transfer to cut surfaces, may allow environmental contaminants to grow rapidly on the fresh-cut product because of elimination of competition *(28)*, particularly at abusive temperatures.

TABLE 4. *Effect of hot-water treatment, irradiation, and storage on color of fresh-cut cantaloupes*[a]

Storage time (days)	Cold water		Hot water	
	0 kGy	0.5 kGy	0 kGy	0.5 kGy
L*				
1	67.0 ± 3.8 A	66.8 ± 3.6 A	68.3 ± 4.4 A	67.5 ± 4.3 A
3	68.0 ± 3.2 AB	67.6 ± 3.4 B	69.0 ± 3.7 A	67.4 ± 2.7 B
7	67.2 ± 3.8 A	66.9 ± 3.9 A	67.6 ± 2.9 A	66.7 ± 2.5 A
LSD[b]	1.5	1.5	1.5	1.3
Hue				
1	63.0 ± 2.8 B	63.9 ± 2.5 AB	64.7 ± 2.3 A	64.8 ± 2.5 A
3	65.3 ± 3.3 AB	64.6 ± 2.9 AB	64.3 ± 1.7 B	65.8 ± 5.3 A
7	64.4 ± 2.3 A	63.9 ± 2.5 A	64.3 ± 1.7 A	64.2 ± 1.5 A
LSD	1.1	1.1	0.8	1.3
Chroma				
1	28.8 ± 3.0 A	27.8 ± 2.9 AB	28.1 ± 3.7 A	26.6 ± 3.0 B
3	27.9 ± 3.7 A	28.0 ± 2.8 A	28.3 ± 2.4 A	27.2 ± 4.2 A
7	28.1 ± 2.6 AB	28.4 ± 2.3 A	27.4 ± 2.1 B	28.1 ± 2.2 AB
LSD	1.2	1.1	1.1	1.3

[a] Whole melons were washed in cold water (20°C) or hot water (76°C) for 3 min. Cut pieces prepared from the washed melons were then exposed to 0 or 0.5 kGy of gamma radiation. Color effects (mean ± SD) were analyzed during subsequent storage at 4°C. Within the same storage period, means with the same letters are not significantly different ($P > 0.05$).

[b] Least significant difference ($P < 0.05$) for the storage effect.

When low doses of radiation are applied to the packaged fresh-cut cantaloupe, the small numbers of surviving organisms and environmental contaminants can be further reduced, thereby reducing the risk of outgrowth during distribution and marketing.

Good manufacturing practices should be followed even when irradiation has been applied. The radiation dose used in the present study was low and eliminated only a small number of native microorganisms. Higher microbial loads may require higher doses to ensure the microbial quality and safety of the product, but these higher doses may cause significant undesirable quality changes.

Sugars represent most of the SSC. Sweetness often determines consumer acceptance of melons *(4)*. Hot-water treatments slightly lowered SSC. However, it is unclear whether consumers would be able to taste the difference. Sensory studies should be conducted to evaluate whether the decreases in SSC are noticeable by consumers. In addition to sweetness, aroma also plays an important role in the acceptance of melons *(3)*. Both heat treatment and irradiation can delay the ripening process of climacteric fruits such as cantaloupe *(17)* and the development of the unique aromas and volatile compounds of many other fruits *(7, 23)*. The effects of hot-water treatment and irradiation on sensory attributes of fresh-cut cantaloupes need further study. Palekar et al. *(22)* found that irradiation at doses up to 1.4 kGy had no significant effect on descriptive texture and flavor attributes.

Hot-water surface pasteurization reduced the population of microorganisms on the surface of whole cantaloupes. Low-dose irradiation applied to fresh-cut melon cubes also reduced the microbial population. Hot-water surface pasteurization of whole cantaloupe combined with low-dose irradiation of the fresh-cut product provided greater microbial reduction than did either treatment alone. The combination of the two treatments had little effect on quality of fresh-cut cantaloupe. Hot-water pasteurization of whole fruit, low-dose irradiation of cut cubes, or the combination of the two treatments can be used to reduce the microbial population and extend the shelf life of fresh-cut cantaloupe while enhancing product safety.

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